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Selecting Ecologically Analogous Forest Stands: A Rigorous Method for Studies of Atmospheric Deposition Effects

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Introduction

Ecologists often attempt to choose ecologically similar study sites as one means of reducing extraneous variation, thereby enhancing the probability of detecting relatively small treatment differences. A variety of sampling techniques and comparison procedures are available to limit the influence of extraneous variation on hypothesis testing. For ecological studies these range from field reconnaissance and comparisons of pertinent community characteristics to intensive spatial sampling techniques. Our approach was to establish appropriate site selection criteria and to use multivariate statistical techniques to rigorously assess quantitative attributes of forest community characteristics. Spatial statistical sampling and analysis is another approach to dealing with this variability, although methodologies are somewhat theoretical. Spatial sampling has the advantage of extending results to a larger geographical frame of reference, with attendant estimates of statistical confidence (Griffith 1984). An important consideration is high sampling cost or, under a fixed-cost scenario, a concomitant reduction in the number of measured attributes.

A well-defined atmospheric deposition gradient is the focus for our and other studies evaluating the potential effects of deposition inputs on forest productivity and health. Such gradient studies, using natural forest stands over large geographical areas, are inherently subject to a wide range of forest community and site variability in addition to atmospheric deposition differences. Our approach to experimental design was to measure a large number of attributes along a spatially narrow deposition gradient in which extraneous (non-deposition-related) variation was initially minimized by pre-selection of ecologically analogous forest stands. This technique is expected to enhance the potential for identifying atmospheric deposition-related effects or conditions at the expense of spatial generalization. Analogous stand selection criteria focused on factors unlikely to have been affected by atmospheric deposition (e.g., forest canopy composition, soil physical properties). Implicit in this scheme is the necessity to quantify and statistically account for remaining extraneous variation within and among selected stands.

The purpose of this research circular is to illustrate and document quantitative, rigorous application of the ecologically analogous site approach to an investigation of potential effects of atmospheric sulfate/nitrate deposition on soil, forest community, and tree growth in oak-hickory forests in Pennsylvania.

Background

Data from a 12-to-16 station statewide monitoring network were used to identify a wet sulfate deposition gradient in northern Pennsylvania each year from 1982 to 1986 (Lynch and Corbett 1983; Lynch et al. 1984, 1985, 1986). The four-year average sulfate deposition was lowest, 23.5 kg/ha/yr, in Tioga and Lycoming Counties, and highest, 39.1 kg/ha/yr, approximately 160 km west in Elk and Jefferson Counties. Ten additional monitoring locations established along the deposition gradient in 1987 will further describe and define the magnitude of wet deposition inputs.

The potential effects of differing atmospheric deposition inputs across this gradient are being studied by evaluating forest community and tree growth variables in ecologically analogous forest stands located along the gradient. The initial objective was to select candidate analogous stands at four approximately equidistant core areas along the deposition gradient. Twenty-one candidate analogous stands were selected for preliminary sampling on the basis of topographic position, forest community characteristics, and soil properties. Qualitative and quantitative data were collected and used for final selection of analogous stands that are most similar with regard to soil physical properties, physiography, forest canopy layer community characteristics, and disturbance history. An intensive evaluation of forest condition and responses to differing levels of wet deposition inputs is being conducted in these stands. These additional data provided a basis for an assessment of stand comparability ("analogousness") to evaluate and verify initial stand selection procedures.

The study area lies within the Allegheny High Plateaus Section of the Appalachian Plateaus Province (Ciolkosz et al. 1983). This deeply dissected plateau has elevations ranging from 305 m in the lowest valleys to 610 m or higher over much of the plateau top.

Approximately 90 percent of the land within the atmospheric deposition gradient study area is forested. The forest types are classified in the oak-hickory major forest-type group (Powell and Considine 1982). Forest stands are generally fully stocked, even-aged, hardwood-dominated, sawtimber-sized stands approximately 60 to 100 years-old. Soils of this area were formed in materials derived from sedimentary rocks of sandstone, shale, and siltstone (Soil Conservation Service 1966, 1986, 1988).

Most forest land in the study area is owned by the Commonwealth of Pennsylvania and is managed by the Department of Environmental Resources, Bureau of Forestry. The study area includes all or part of four state forests; from west to east along the gradient these are: Clear Creek, Moshannon, Sproul, and Tiadaghton State Forests. Each of these will be referred to as a "core area," with core area 1 at the western end (Clear Creek) and core area 4 at the eastern end (Tiadaghton).

Methods

Preliminary Stand Evaluations and Sampling

Qualitative evaluations. A qualitative survey of the atmospheric deposition gradient study area was conducted to identify a community/site type commonly found at all locations (Fig. 1). Topographic position, elevation, and overstory forest community composition were the major attributes considered. Pennsylvania Bureau of Forestry district foresters were consulted with regard to the forest composition and site characteristics in their respective districts. Forest stands matching the identified community/site type served as the population of stands from which candidate stands were selected for on-site examination.

In order that potential changes in long-term growth trends could be evaluated, candidate stands were limited to include only even-aged mature stands >60 years old, and stands which had been unmanaged for timber production, i.e. no evidence of intermediate treatments. Because of the intensive studies to be conducted after final selection of analogous stands, accessibility and proximity to a deposition monitoring station were also considered.

Bureau of Forestry district foresters were subsequently contacted for assistance in locating suitable candidate stands for on-site examination. Stand compartment maps showing species composition, size class, site quality class, and approximate stand boundaries were available for most state forest land. When these maps were not available, candidate stands were located using USGS 7.5′ topographic maps or state forest public use maps. Only stands 5 ha and larger were considered.

On-site examination of candidate stands was conducted to evaluate topographic position, overstory species composition, soil texture, age structure, and disturbance history. If a candidate stand met the established criteria, it was sampled. Stands that were unsuitable for sampling (noncriteria stands) were marked on topographic maps and the reason(s) for not sampling was recorded. Each candidate stand was named by the 7.5′ topographic quadrangle on which it occurred and by a number indicating the order in which it was examined e.g., the candidate stand named Sigel 2 was the second stand examined on the Sigel quadrangle. A minimum of four stands was sampled in each core area.

Sampling procedures. Before sampling, approximate stand boundaries were determined and sketched on a 7.5′ topographic map. Plot centers for variable radius prism plots were established at 100 to 200 m intervals along a compass bearing transecting the stand. The number of prism plots used to characterize a stand was approximately proportional to the stand size. At each plot center, a 2.5 m^2/ha prism plot was used to characterize overstory species composition, stand density and stocking. The species, diameter at 1.3 m, crown

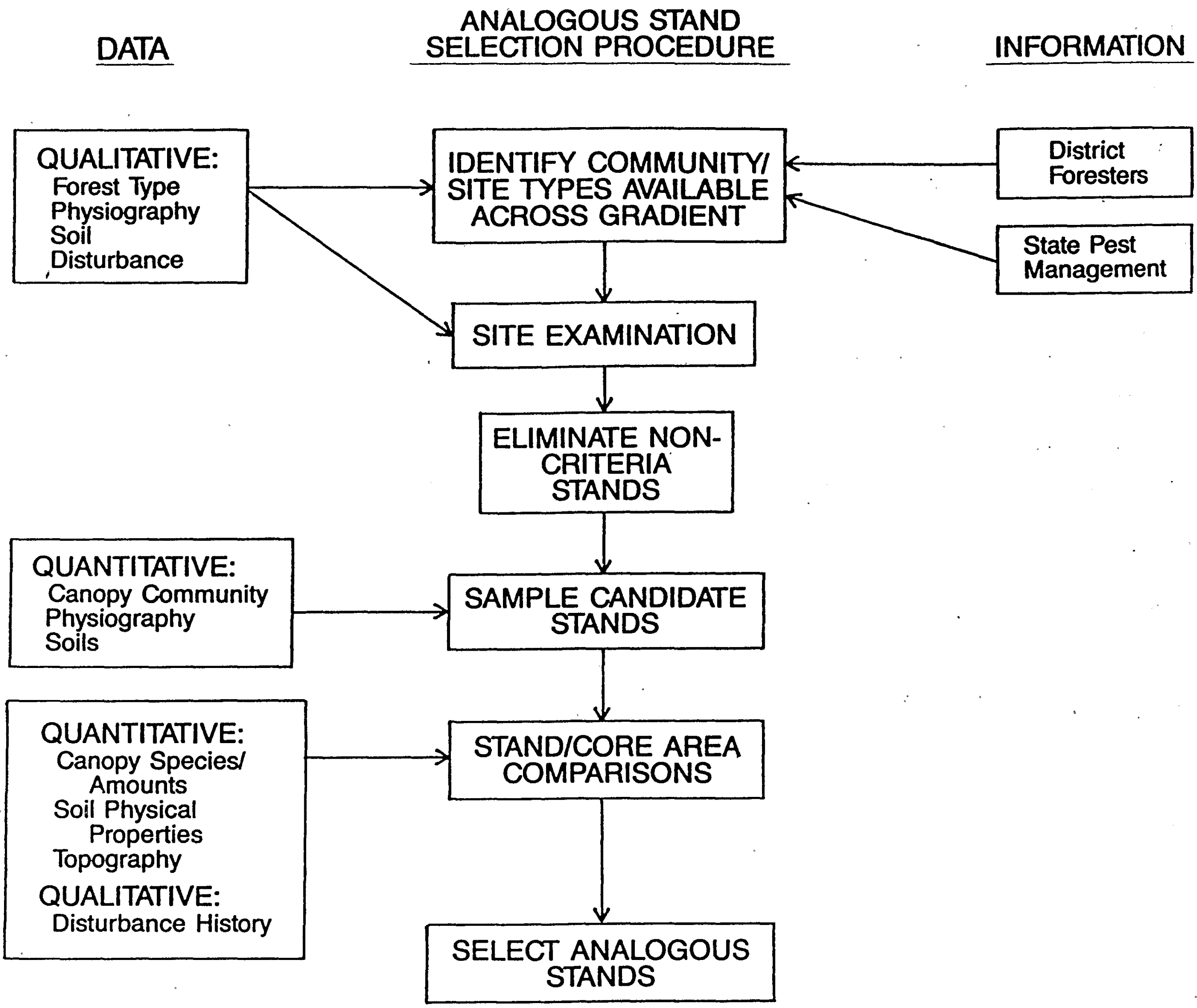

Figure 1. Flow diagram of analogous stand selection procedure.

class, and live/dead status were recorded for each tree within the prism plot. Only trees in the dominant, codominant and intermediate crown classes were measured. The height and age of a northern red oak (*Quercus rubra* L.) and/or white oak (*Q. alba* L.) tree in the dominant or codominant crown class were recorded for each plot. The tree(s) closest to plot center with a clearly visible upper crown was used for height and age determination. Height was measured with a clinometer, and age was estimated from an increment core extracted at a height of 1.3 m on the bole of the tree. Increment cores were examined in the field to insure that the core intersected the pith. All age estimates were verified by sanding cores and counting rings in the laboratory. Site index was calculated for each stand using equations derived for upland oaks (Schnur 1937). At each plot center slope was measured with a clinometer, aspect was determined with a compass, and elevation was estimated from a USGS 7.5′ topographic map. All measurements followed methods described by Zedaker and Nicholas (1986).

Within each sampled candidate stand one or more soil pits approximately 60 cm deep were dug in association with selected prism plots. The thickness (cm) and an estimate of percent stoniness by volume of the major horizons (A_1 A_2, B_1, B_2, and B_3 if present,) were recorded. Observations on the total rooting depth, depth to impeded drainage, and mottling were noted for each soil pit. Samples were taken for the combined A_1 and A_2 horizons, the B_1 horizon, and the B_2 horizon for laboratory analysis. Soil series were identified from county soils maps and consultation with Soil Conservation Service personnel.

Laboratory procedures. Soil samples were air dried, gently ground, and the <2-mm fraction was saved for analysis. A sub-sample was sent to the Research Extension Analytical Laboratory at OARDC for determination of percent organic matter (Page et al. 1982). Standard textural analysis was performed in our laboratory to determine percent sand, silt, and clay (Black 1965).

Stand disturbance history. The Division of Forest Pest Management, Bureau of Forestry has provided detailed histories of past insect and disease outbreaks in or near the candidate stands from 1960 to present. Records generally date to the mid-1960's and are of variable quality. Annual aerial surveys were conducted in mid-to late-summer to produce sketch-maps with estimates of the degree of defoliation as light (0 to 30% defoliation), moderate (31 to 60% defoliation), or heavy (>60% defoliation). These estimates, the probable causal agent, and approximate area defoliated were recorded. This information was used during final site selection to qualitatively identify sites with similar disturbance histories.

Selection of Analogous Forest Stands

Stand-specific environmental and forest community variables were estimated from plot data collected in each candidate stand. A series of analyses was used to compare the similarity and uniqueness of individual plots, stands (data averaged over plots within candidate stands), and core areas (data averaged over candidate stands at each of the four gradient core areas). Environmental/site variables and forest canopy composition variables (with data for each species expressed as stems/ha, basal area/ha, and importance value) were compared using multivariate methods (Gauch 1982; McClenahen and Brown 1988) (Fig. 2). Importance values were calculated by summing the relative basal area/ha and relative stems/ha for a species and dividing by two (to put the values on a 0 to 100% scale). Variables used in this process are assumed to be non-response variables, i.e. environmental and forest community measures which are not expected to have been altered by atmospheric deposition inputs. These variables include slope steepness, aspect, elevation, percent stoniness and horizon thickness, texture, and percent organic matter. Overall objectives were to assess the variability and extent of comparability among the potential and final set of analogous stands, and to retain the greatest possible overlap in non-response variable attributes across core areas.

Analysis of environmental/site variables. Stepwise discriminant, centroid cluster, and detrended correspondence analyses compose the primary techniques for comparing and contrasting stands and core areas on the basis of non-response environmental variables (Jennrich and Sampson 1983; Pielou 1984; Hill 1979a).

Environmental variables were examined using centroid cluster analyses to determine whether unusual or "outlier" stands were apparent based on the amalgamation distances and the corresponding

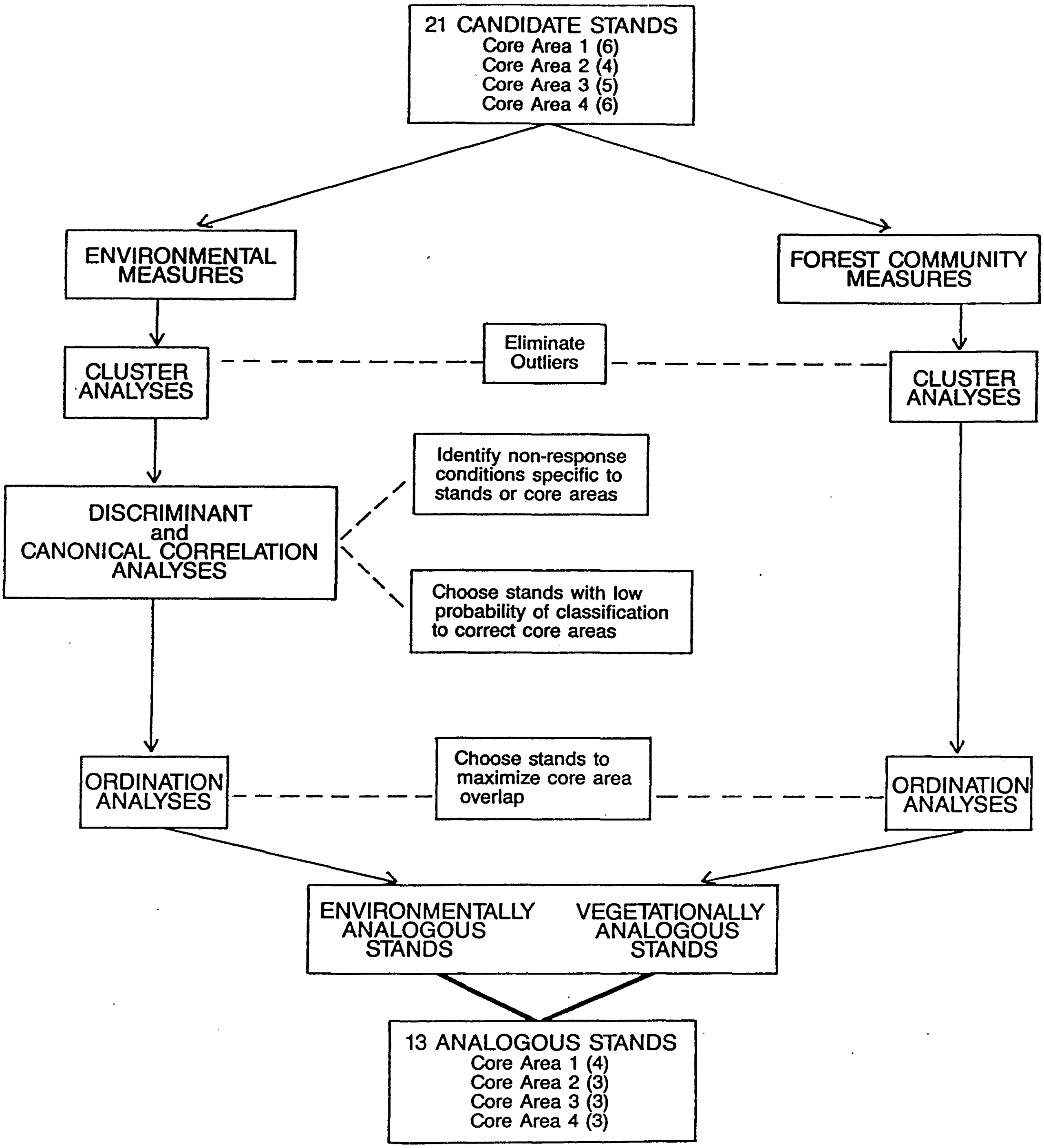

Figure 2. Flow model of sequential candidate stand screening and selection procedures. Dashed lines link purpose or objectives associated with the analytical methods.

dendrogram. Cluster analyses were run separately on the following four data sets: topographic, A horizon, B_1 horizon, and B_2 horizon variables. Topographic variables were the stand-averaged percent slope, aspect, and elevation. Variables measured in the A horizon and used for analysis were the percent organic matter, percent sand, silt, and clay, combined thickness of A_1+A_2 horizons, percent stoniness of A_1 horizon, and percent stoniness of A_2 horizon. B_1 horizon variables used were the percent organic matter, percent sand, silt, and clay, and thickness and percent stoniness of B_1 horizon. B_2 horizon variables included percent organic matter, percent sand, silt, and clay, and percent stoniness. This provided a total of 21 non-response variables that were evaluated. Resulting dendrograms were examined to determine whether stands from specific core areas clustered together and whether obvious outlier stands were identifiable.

Stepwise discriminant analyses of the same environmental variables in the four data sets were used to determine whether any variables could be used to classify stands into their correct core area. Absence of significant discriminant functions or poor discriminant functions (those with high rates of misclassification) was interpreted as indicating similar environmental conditions at the respective stands.

Subsequently, all the environmental variables were re-scaled and expressed as a percentage of the maximum value for the particular variable. The data were combined so that a total of 21 environmental variables was used with detrended correspondence analysis (DCA) to ordinate the 21 stands and 21 environmental variables with the program DECORANA (Hill 1979a). The plotted ordination based on stand scores for the first two axes was examined to determine which stands were dissimilar (peripherally located) and which were similar (nearest to each other). Peripherally located stands were noted for comparison with results of stand vegetation ordinations.

Analysis of vegetation variables. Prism plot overstory data (stems/ha, basal area/ha, and importance value) by species formed the basis for comparison of forest community variables. Data from each stand were transformed and expressed on a percentage basis by species, (e.g., relative basal area/ha of a species, and relative stems/ha of a species). Two-way indicator species analyses using the program TWINSPAN (Hill 1979b) were used to determine whether stands from core areas clustered together or were mixed with stands from other core areas. Separate analyses were used to compare living basal area/ha, stems/ha, and importance values of species in their respective stands. Individual stands which did not cluster with other stands until final clustering stages were considered outliers and were eliminated from further consideration.

Amounts of living basal area/ha and stems/ha for species in each stand were subsequently used in DCA ordinations performed with DECORANA (Hill 1979a). Stand scores were plotted on the first two DCA axes to identify dissimilar, peripherally located stands and those most similar or closest together.

To assess the importance of overstory mortality in respective stands, dead trees, regardless of species, were combined as a single pseudospecies for both TWINSPAN and DECORANA analyses. These analyses were compared with those based on living trees to determine whether tree mortality substantially altered the classifications and ordinations.

Final stand selection involved comparisons of stand ordinations based on environmental and vegetation variables, consideration of overall study objectives, a qualitative assessment of disturbance history, and the constraint of a three-stand-per-core-area minimum necessary for this study (Fig. 2).

Assessment/Verification of Stand Comparability

Sampling procedures. After the selection of analogous stands, boundaries were established so that plot centers could be randomly located using a grid system. A minimum of 10 plots was established in stands <20 ha and approximately 1 plot/2 ha was established in stands >20 ha for detailed characterization of stand composition, stocking, and density. From the center stake marking the plot center, a 12-m-radius plot was used to record all standing trees ≥ 2.5 cm dbh. For each tree in the plot, data were recorded as described previously except trees in the suppressed crown class were measured. The following physiographic and soils data were also obtained by methods described previously. Slope, aspect, and elevation were recorded at each plot. In each analogous stand 3 to 7 soil pits were sampled and described in locations across the range of topographic variation. Soil physical properties (except percent of organic matter) were determined.

Analysis of environmental/site variables. These variables, consisting of horizon thickness, percent stone by volume, textures for A, B_1, and B_2 horizon samples, slope steepness, aspect, and elevation, were analyzed with centroid cluster analyses and stepwise discriminant analyses as described previously.

Analysis of vegetation variables. A nested analysis of variance fixed effects model (core area and stands nested in core area with plots as observations) was used to evaluate differences in stand basal area (m^2/ha) and density (stems/ha) of all living overstory stems (Neter et al. 1985). Separate analyses were conducted on dead trees. DCA ordinations were used to assess overall stand similarity with regard to density and stocking (Hill 1979a, Gauch 1977).

DCA was used to evaluate species composition in the analogous stands. Data were summarized and analyses performed on a stand average basis with data from individual plots averaged to determine the stems/ha and basal area/ha of species present. DCA axes 1 and 2 were used to ordinate the sample scores in low dimensional space. Graphs of these ordinations were examined to determine the presence of outliers and to compare with the results of classification analyses using TWINSPAN (Hill 1979b). TWINSPAN analyses were used to determine whether any stand or plot samples from a particular core area consistently clustered together at the first division. Data were expressed as described previously.

Verification analyses. Assessment of stand comparability was accomplished with methods similar to the stand selection procedure. Because stands were selected based on overstory communities (dominant, codominant, and intermediate crown classes), analogousness was assessed using data limited to these crown classes. Initial stand selection analyses used dead trees as a single pseudo-species. Only dead trees still in the canopy were recorded in the initial stand sampling; however, all standing dead trees $\geq$2.5 cm dbh were recorded in the more intensive stand sampling. For this reason, only living trees were used in the verification analyses. In addition to analyses based on stand-averaged data, ordinations and classifications based on plot averages were examined. The amount of overlap between stand vegetation characteristics was graphically assessed and compared with results of analyses of variance and classification analyses. Finally, comparisons between the initial stand selection results and verification analyses were used to assess the adequacy of the initial stand selection procedures and, if necessary, to recommend alteration of these procedures.

Results

Preliminary Evaluations

Stand selection criteria. A qualitative survey of the gradient study area resulted in the identification of predominantly red oak stands on upland sites as the community/site type commonly found at all locations. Candidate analogous stands were limited to areas from 450 to 675 m in elevation since most deposition monitoring sites are located within this range. In addition to the even-aged and >60 years age requirement, only stands with relatively gradual slopes from 0° to 10° were considered. Finally, only sites with medium textured surface soils and no apparent impeded drainage were considered.

Fifty-seven stands were examined to determine whether they met the established criteria for sampling. Stands with acceptable community composition, age structure, and topographic characteristics were more readily available in the western part (core areas 1 and 2) of the gradient than in the eastern part (core areas 3 and 4). In core areas 2, 3, and 4, oak leaftier (*Croesia semipurpurana* (Kearfott)) and oak leafroller (*Archips semiferanus* (Walker)) outbreaks in the late 1960's and early-to-mid 1970's resulted in substantial mortality in some stands (Ellenberger and Cameron 1977). In addition, most accessible stands in this area are managed for timber production.

The most common reasons for initially rejecting stands as candidate analogous stands were unsuitable species composition and evidence of disturbance. Stands were frequently rejected because northern red oak was not the dominant oak species. Stands with dense mountain laurel (*Kalmia latifolia* L.) or atypical species such as white birch (*Betula papyrifera* Marsh.) were rejected. Other stands were rejected because of disturbances which were indicated by a high proportion of standing dead and/or downed timber and the presence of cut stumps.

Stands selected for sampling. From the 57 candidate stands examined, 21 were sampled as candidate analogous stands. The specific location

Table 1. Geographic location of 21 candidate analogous stands.

Core Area	Stand Name[1]	Stand Code	County	Township	Latitude	Longitude
Clear Creek	Sigel 3	C1	Jefferson	Heath	41°19′ 15″	79°04′
	Sigel 5	C2	Jefferson	Heath	41°20′	79°04′
	Sigel 7	C3	Jefferson	Heath	41°19′ 45″	79°03′ 30″
	Munderf 1	C4	Jefferson	Polk	41°17′ 45″	78°59′ 30″
	Munderf 2	C5	Jefferson	Polk	41°18′	78°59′
	Munderf 5	C6	Jefferson	Heath	41°19′	78°58′
Moshannon	Huntley 1	M1	Clearfield	Pine	41°08′ 15″	78°29′ 30″
	Huntley 2	M2	Elk	Jay	41°14′ 45″	78°26′
	Elliott Park 2	M3	Clearfield	Pine	41°14′ 45″	78°32′ 30″
	Elliott Park 3	M4	Clearfield	Pine	41°07′	78°30′ 45″
Sproul	Glen Union 1	S1	Clinton	Grugan	41°22′ 30″	77°33′ 45″
	Young Womans Creek 1	S2	Clinton	Chapman	41°24′ 30″	77°37′ 45″
	Young Womans Creek 2	S3	Clinton	Leidy	41°25′ 45″	77°41′ 15″
	Hammersley Fork 2	S4	Clinton	Leidy	41°28′	77°59′
	Hammersley Fork 3	S5	Clinton	Leidy	41°27′ 45″	77°58′ 15″
Tiadaghton	Slate Run 1	T1	Lycoming	McHenry	41°24′ 45″	77°33′ 15″
	Slate Run 5	T2	Clinton	Chapman	41°28′ 30″	77°36′ 15″
	Bodines 1	T3	Lycoming	Cascade	41°27′ 45″	76°57′ 15″
	Bodines 2	T4	Lycoming	Cascade	41°27′ 30″	76°57′ 15″
	Trout Run 2	T5	Lycoming	McIntyre	41°27′ 45″	77°02′ 15″
	Trout Run 3	T6	Lycoming	McIntyre	41°27′ 45″	77°02′

[1]The stand name refers to the topographic quadrangle map on which the stand is located and the number refers to the order in which stands were examined on that quadrangle.

of these 21 stands is provided in Table 1 and Figure 3. Quantitative data for each stand are summarized in Tables 2a-2d. Because of the difficulty in locating acceptable candidate stands at the eastern end of the study area, three stands with characteristics that deviated slightly from the established criteria were sampled. Intermediate treatments, such as thinnings and/or salvage operations, had been conducted in these stands.

Core area summaries. Red oak was the dominant species in terms of basal area (m^2/ha) in all stands except S2, S3 (core area 3) and T1, T2, T3, and T5 (core area 4) (Tables 2c, 2d). In these stands red maple (*Acer rubrum* L.) basal area was slightly greater than red oak basal area.

Total stand basal area varied among the 21 candidate stands. Stand T1 (core area 4) has the lowest total basal area, 17.8 m^2/ha (Table 2d). This stand was thinned in the 1970's and does not have a closed canopy. Thinning was also evident in stands S2 and S3 (core area 3; Table 2c). These stands were defoliated by oak leaftier and oak leafroller in the late 1960's and 1970's and subsequently salvageable trees were harvested. The smallest stand sampled, stand T6 (core area 4; Table 2d), was approximately 5 ha, and had the largest total stand basal area, 31.3 m^2/ha.

Site indices for upland oaks (Schnur 1937) indicated variation in site quality. This variation was greatest among core area 4 stands where site index ranged from 16.2 at T4 to 22.9 at T2 (Table 2d). A potential site quality gradient was noted in examining the mean site indices by core area: Clear Creek, 24.1, Moshannon, 21.3, Sproul, 21.5, and Tiadaghton, 19.1.

Topographic characteristics for each core area do not vary substantially (Table 3). There is considerable variation in site exposure as measured by azimuth. However, since most stands are relatively level,

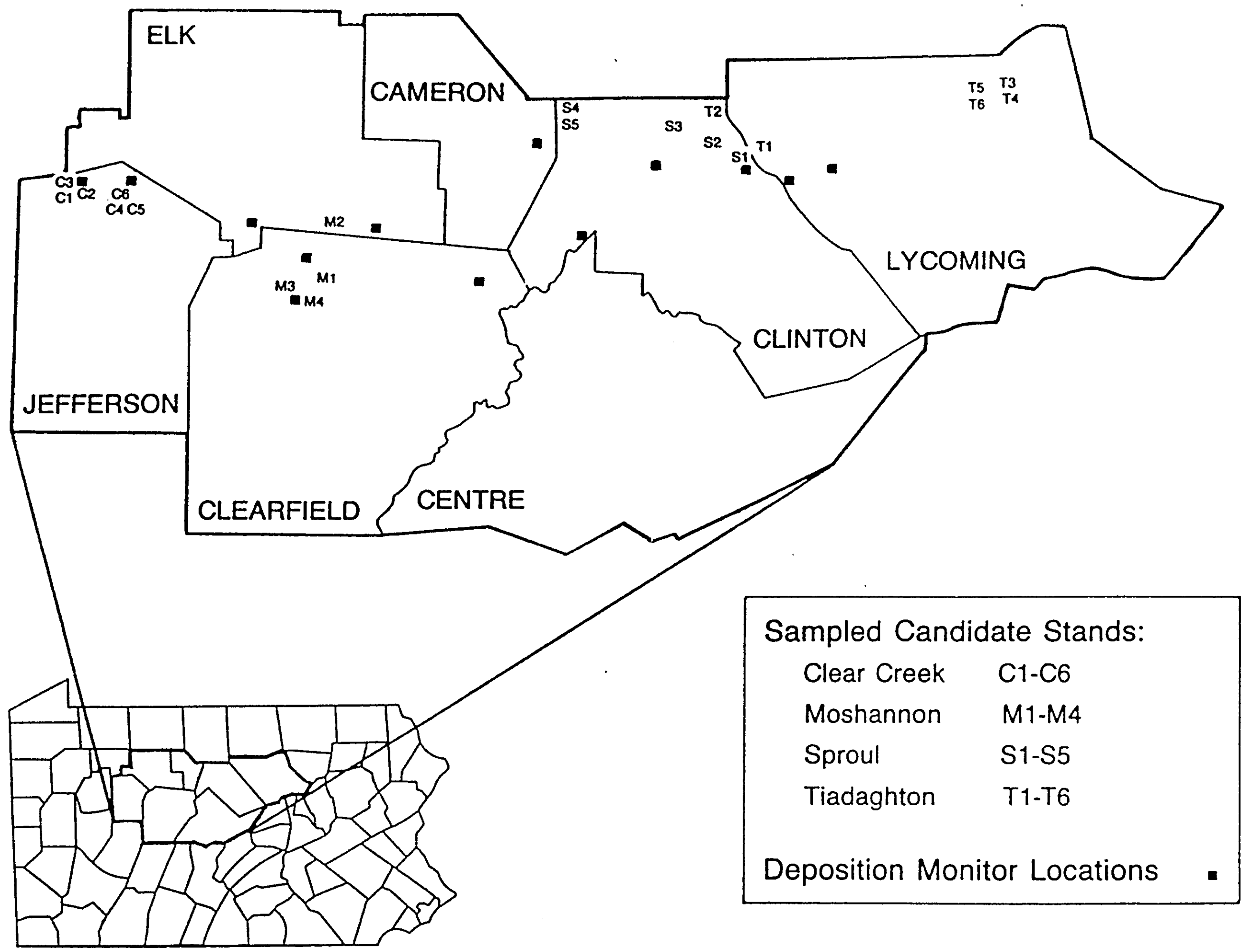

Figure 3. Location of 21 sampled candidate stands and 13 deposition monitors along the atmospheric deposition gradient in northern Pennsylvania.

Table 2a. Descriptive data for 6 stands sampled in Clear Creek State Forest (core area 1; western end of sulfate gradient). Values shown for slope, elevation, basal area, height, age, and site index are averages calculated by stand; aspect values are medians.

Stand Name	Sigel 3	Sigel 5	Sigel 7	Munderf 1	Munderf 2	Munderf 5
Stand Code	C1	C2	C3	C4	C5	C6
Aspect	223.0°	235.0°	226.5°	117.0°	169.0°	82.0°
Slope	6.6°	3.6°	4.0°	4.6°	4.4°	4.6°
Elevation (m)	500.5	509.6	493.7	541.9	552.9	539.2°
Area (ha)	27.8	24.6	9.3	19.3	8.9	11.1
Basal Area (m^2/ha)						
N. Red Oak	10.8	6.4	17.8	15.6	14.2	18.8
White Oak	6.2	6.4	2.9	6.9	3.2	1.8
Scarlet Oak	0	11.5	2.9	0	1.8	0.9
Chestnut Oak	6.9	0.9	0	2.3	2.3	1.8
Red Maple	0.6	2.7	0	0	1.8	0.9
Other	1.3	0.5	0.6	3.7	0	4.6
Total	25.8	28.4	24.1	28.4	23.3	29.4
No. Plots	7	5	4	5	5	5
Age (years)						
N. Red Oak	78	72	79	69	64	70
White Oak	79	71	77	—	88	—
Height (m)						
N. Red Oak	29.6	28.9	28.9	29.3	26.6	32.1
White Oak	25.6	29.3	24.7	—	25.3	—
Site Index (m)	22.7	24.7	23.4	24.8	22.2	27.1
Soil Series	DeKalb	DeKalb	DeKalb	DeKalb	DeKalb	DeKalb

Table 2b. Descriptive data for 4 stands sampled in the Moshannon State Forest (core area 2). Values shown for slope, elevation, basal area, height, age, and site index are averages calculated by stand; aspect values are medians.

Stand Name Stand Core	Huntley 1 M1	Huntley 2 M2	Elliott Park 2 M3	Elliott Park 3 M4
Aspect	164.0°	340.0°	159.5°	96.0°
Slope	2.5°	2.6°	2.0°	2.0°
Elevation (m)	661.4	580.0	634.0	662.0
Area (ha)	37.4	39.7	17.5	19.6
Basal Area (m^2/ha)				
N. Red Oak	14.9	18.3	13.2	17.9
White Oak	4.0	1.7	1.1	2.3
Scarlet Oak	0.6	0	0	0
Chestnut Oak	0	0	0.6	0
Red Maple	5.7	1.7	8.0	5.9
Other	1.1	0	2.9	1.8
Total	26.3	21.7	25.8	27.9
No. Plots	4	4	4	5
Age (years)				
N. Red Oak	68	76	71	67
White Oak	69	83	—	—
Height (m)				
N. Red Oak	22.6	28.0	26.5	25.0
White Oak	22.3	28.0	—	—
Site Index (m)	19.0	22.7	22.4	21.1
Soil Series	Cookport/ Hazleton	Cookport/ Hazleton/ Clymer	Cookport/ Hazleton	Clymer Cookport

Table 2c. Descriptive data for five stands sampled in the Sproul State Forest (core area 3). Values shown for slope, elevation, basal area, height, age, and site index are averages calculated by stand; aspect values are medians.

Stand Name	Glen Union 1	Young Women's Creek 1	Young Women's Creek 2	Hammersley Fork 2	Hammersley Fork 3
Stand Code	S1	S2	S3	S4	S5
Aspect	57.5°	143.8°	310.0°	133.3°	84.8°
Slope	3.8°	2.0°	1.0°	2.5°	2.1°
Elevation (m)	566.9	559.6	584.3	624.8	591.3
Area (ha)	12.7	106.9	68.5	13.2	57.6
Basal Area (m^2/ha)					
N. Red Oak	17.2	5.0	7.6	16.1	14.6
White Oak	0.6	2.3	0	2.3	2.6
Scarlet Oak	0	0	0	0	0
Chestnut Oak	0	0	0	0	0
Red Maple	3.4	9.9	16.8	5.7	8.3
Other	0.6	3.4	0.8	1.1	2.0
Total	21.8	20.6	25.2	25.2	27.5
No. Plots	4	6	3	4	8
Age (years)					
N. Red Oak	68	69	81	69	66
White Oak	69	72	—	70	69
Height (m)					
N. Red Oak	22.6	25.0	26.8	24.4	25.9
White Oak	22.3	24.4	—	27.4	25.3
Site Index	23.4	20.6	21.0	20.8	21.4
Soil Series	Cookport/ Hazleton/ Clymer	DeKalb	DeKalb	DeKalb/ Albrights	Dekalb/ Cookport

Table 2d. Descriptive data for 6 stands sampled in the Tiadaghton State Forest (core area 4; eastern end of sulfate gradient). Values shown for slope, elevation, basal area, height, age, and site index are averages calculated by stand; aspect values are medians by stand.

Stand Name Stand Core	Slate Run 1 T1	Slate Run 5 T2	Bodines 1 T3	Bodines 2 T4	Trout Run 2 T5	Trout Run 3 T6
Aspect	188.0°	242.0°	300.0°	91.0°	344.0°	146.0°
Slope	4.6°	3.0°	3.0°	3.7°	3.7°	2.7°
Elevation (m)	594.4	550.9	588.0	604.5	489.7	506.0
Area (ha)	14.2	5.2	13.4	6.7	6.5	5.0
Basal Area (m^2/ha)						
N. Red Oak	5.5	11.5	8.7	14.2	5.3	15.3
White Oak	1.4	0	0	0.4	0.8	0
Scarlet Oak	0	0	0	0	0	0
Chestnut Oak	1.8	0	4.1	5.7	6.1	8.4
Red Maple	7.3	13.2	9.2	2.7	6.1	3.0
Other	1.8	5.7	3.7	1.1	2.3	4.6
Total	17.8	30.4	25.7	24.1	20.6	31.3
No. plots	5	4	5	6	3	3
Age (years)						
N. Red Oak	79	80	70	85	65	86
White Oak	—	—	—	—	—	—
Height (m)						
N. Red Oak	24.1	28.3	22.9	20.4	26.9	23.2
White Oak	—	—	—	—	—	—
Site Index (m)	19.4	22.9	19.3	16.2	18.5	18.1
Soil Series	Leck Kill/ Clymer	Leck Kill/ Clymer	Oquaga/ Lordstown	Oquaga/ Lordstown	Oquaga/ Lordstown	Oquaga/ Lordstown

Table 3. Mean ($\bar{X}$), standard deviation (S.D.) and range of slope and elevation, and median and range of aspect in 21 sampled stands in four core areas.

	Aspect		Slope			Elevation		
Core Area	Median	Range	$\bar{X}$	S.D.	Range	$\bar{X}$	S.D.	Range
	.... degrees		.... degrees			.... m		
Clear Creek	190	40 — 270	4.8	1.7	2 — 9	521.5	24.3	493 — 553
Moshannon	161	3 — 350	2.3	1.1	0 — 4	633.8	34.3	572 — 663
Sproul	90	0 — 340	2.3	1.3	0 — 5	583.6	22.8	547 — 629
Tiadaghton	202	5 — 356	3.5	1.6	1 — 7	565.3	42.4	486 — 608

exposure may have minor influence on tree growth and site quality.

Soil textures varied considerably both within and among core areas (Table 4). In the A horizon the Moshannon core area had the highest mean percent sand, 50.8%, while the Tiadaghton core area had the lowest, 32.2%. The percent clay increased in the deeper horizons at all of the core areas. Mean horizon depths did not vary substantially among core areas, though considerable variation was evident within all core areas. The B_1 mean horizon depth was greater in the Tiadaghton core area than in the other three core areas. A soil pit sampled in stand T6 had the highest organic content (26.8%) in the A horizon. This may have been a sampling artifact caused by the approximately 90% stone in this horizon.

Selection of Analogous Forest Stands

Analysis of environmental/site variables. Centroid cluster analyses of environmental variables did not indicate any obvious outlier stands. Topographic variables did not show a consistent clustering of stands into core areas or indicate any obvious outliers (Fig. 4a). For the B1 horizon variables, stands in the Tiadaghton core area clustered together (Figure 4b).

Stepwise discriminant analyses with the four data sets (topographic variables, A, B_1, and B_2 horizon variables) identified specific topographic and B_1 horizon variables as significant in discriminant functions. The thickness and percent organic matter of the B_1 horizon were the significant variables in the B_1 horizon discriminant function. Ten stands were misclassified in the jackknifed classification (Table 5). Percent slope and elevation were the significant variables in the topographic discriminant function. Five of the 21 stands were misclassified in the jackknifed classification (Lachenbruch and Mickey 1968) (Table 5).

Stand scores of the 21 re-scaled environmental variables were ordinated on the first two DCA axes (Figure 5) and identified six peripherally located or dissimilar stands: T5, T1, M4, T3, T4, and T6. No stands were considered for elimination until comparisons with vegetation analyses were completed.

Analysis of vegetation variables. Two-way indicator species analysis (TWINSPAN) of prism plot overstory vegetation data using relative stems/ha, relative basal area/ha, and importance values for species in their respective stands did not indicate any obvious outlier stands (Tables 6a-6c). These analyses used live trees, and all dead trees treated as a single pseudo-species. A separate analysis with live trees only did not reveal major differences from results shown in Tables 6a-6c. A vegetation community gradient was apparent from these analyses. At the first division, stands from Tiadaghton showed a general tendency to group separately from most other stands. Stands from the Clear Creek, Moshannon and Sproul core areas were split in their membership depending on the variable used for classification (e.g. stems/ha, basal area/ha, importance values) and whether the dead tree pseudo-species was included or excluded from the analysis.

Stands in the Tiadaghton core area had greater basal area/ha and stems/ha of chestnut oak (*Q. prinus* L.), white ash (*Fraxinus americana* L.), and black birch (*Betula lenta* L.) than stands in the Clear Creek core area (Tables 6a and 6b). Stands in the Clear Creek core area had larger components of white, scarlet (*Q. coccinea* Muench.), and black oak (*Q. velutina* Lam.) and less red maple than stands in the Tiadaghton core area. Stands in the Clear Creek core area had a greater percentage of basal area in dead trees (all species combined) than stands in the Tiadaghton core area (Table 6b). TWINSPAN results based on importance values that use both stems/ha and basal area/ha showed only one stand with a different classification (Table 6c). Stand C1 in the Clear Creek core area clustered with the Tiadaghton stands in the first step of the analysis using importance values. This stand had no dead trees and more chestnut oak than any of the other Clear Creek stands.

Stand ordinations based on separate analyses for basal area/ha and stems/ha were plotted on the first two DCA axes. The peripheral location of stands T2, T5, T6, S3, C1, C2, and M4 based on stand scores of stems/ha is indicated in Figure 6a. The peripheral location of stands T2, S2, S3, and C2 based on basal area/ha is shown in Figure 6b. While there is some redundancy in ordinations (stands T2, C2 and C3), stand S2 was peripherally located only in the basal area/ha ordination. Stands M4, T5, T6, and C2 were the stands in the stems/ha ordination that were similar in the basal area/ha ordination. The results of ordinations with live trees only did not differ appreciably from those shown in Figure 6, where dead trees were included as a pseudo-species.

Like the TWINSPAN classifications, the ordinations show a vegetation

Table 4. Soil textures (percent sand, silt, and clay) and depth of A and B_2 horizons for soils sampled in association with 21 forest stands in four core areas. Values shown are mean ($\overline{X}$), standard deviation (S.D.) and range.

CORE AREA (n)[1]	Horizon	TEXTURE									HORIZON DEPTH		
		SAND			SILT			CLAY					
		$\overline{X}$	S.D.	Range	$\overline{X}$	S.D.	Range	$\overline{X}$	S.D.	Range	$\overline{X}$	S.D.	Range
Clear Creek	A	34.3	14.8	19—69	41.8	9.5	20—53	23.9	6.8	11—35	9.5	3.2	3—15
	B_1	32.7	14.2	12—64	36.8	7.0	21—43	30.6	8.8	15—46	13.6	2.6	10—18
(n=13)	B_2	33.3	4.1	11—67	34.6	6.2	18—41	32.1	10.0	15—54	—[2]	—[2]	—[2]
Moshannon	A	50.8	11.1	40—68	32.8	8.1	20—44	16.3	5.1	9—22	10.3	3.4	5—15
(n=6)	B_1	44.2	11.8	28—62	27.8	8.7	16—39	28.0	3.9	22—33	17.8	5.9	11—25
	B_2	44.2	13.1	28—68	27.7	8.2	12—35	28.2	6.2	20—39	—[2]	—[2]	—[2]
Sproul	A	43.6	9.0	28—52	37.0	4.1	30—41	18.9	11.7	8—38	10.4	3.1	6—14
(n=8)	B_1	34.9	9.1	20—44	32.9	5.0	22—38	32.3	11.0	20—49	14.8	4.3	9—23
	B_2	38.1	10.6	19—51	33.1	7.2	18—40	29.0	8.8	20—41	—[2]	—[2]	—[2]
Tiadaghton	A	32.2	13.6	16—51	47.2	7.4	38—61	20.6	9.5	8—35	9.8	3.0	5—16
(n=10)	B_1	29.5	4.5	9—52	39.5	6.1	27—49	31.0	10.1	20—48	23.8	6.4	16—34
	B_2	28.2	16.6	0—51	38.7	7.3	25—47	33.1	14.4	21—65	—[2]	—[2]	—[2]

[1]Number of soil pits samples in each core area.
[2]The B_3 or C horizon was not observed in most soil pits and depth of the B_2 horizon could not be consistently determined.

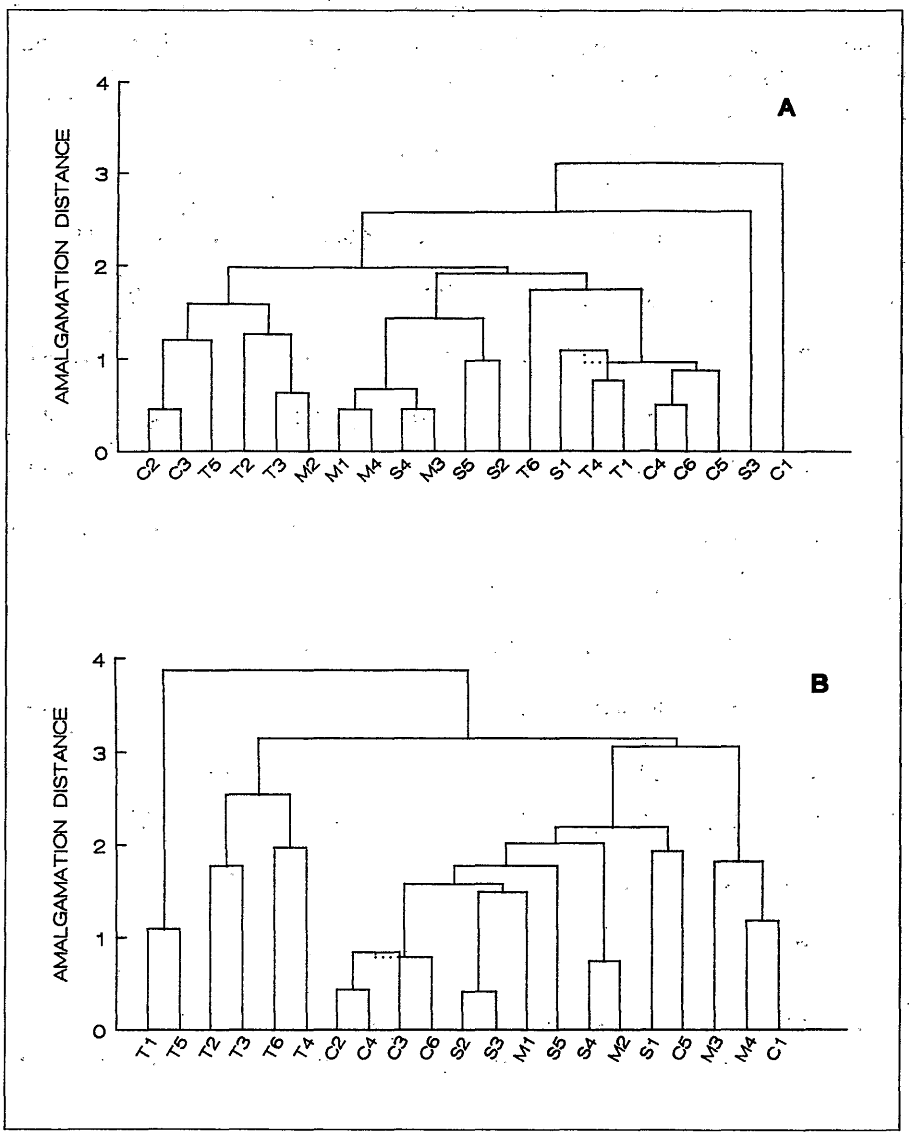

Figure 4. **A:** Dendrogram of centroid cluster analysis based on topographic variables. **B:** Dendrogram of centroid cluster analysis based on B_1 horizon variables.

Table 5. Summary of jackknifed classifications derived from discriminant functions for B_1 horizon variables and topographic variables. Numbers indicate the core area in which the stand was classified where: 1=Clear Creek, 2=Moshannon, 3=Sproul, 4=Tiadaghton.

Core Area	Stands	B_1 Discriminant Classification	Topographic Discriminant Classification
Clear Creek	C1	1	1
	C2	1	1
	C3	1	1
	C4	1	1
	C5	2	1
	C6	1	1
Moshannon	M1	2	2
	M2	2	3
	M3	3	2
	M4	3	2
Sproul	S1	1	4
	S2	2	3
	S3	2	3
	S4	2	2
	S5	3	3
Tiadaghton	T1	2	4
	T2	4	3
	T3	2	4
	T4	4	4
	T5	2	1
	T6	4	4
% Correct Classifications		52.4	76.2

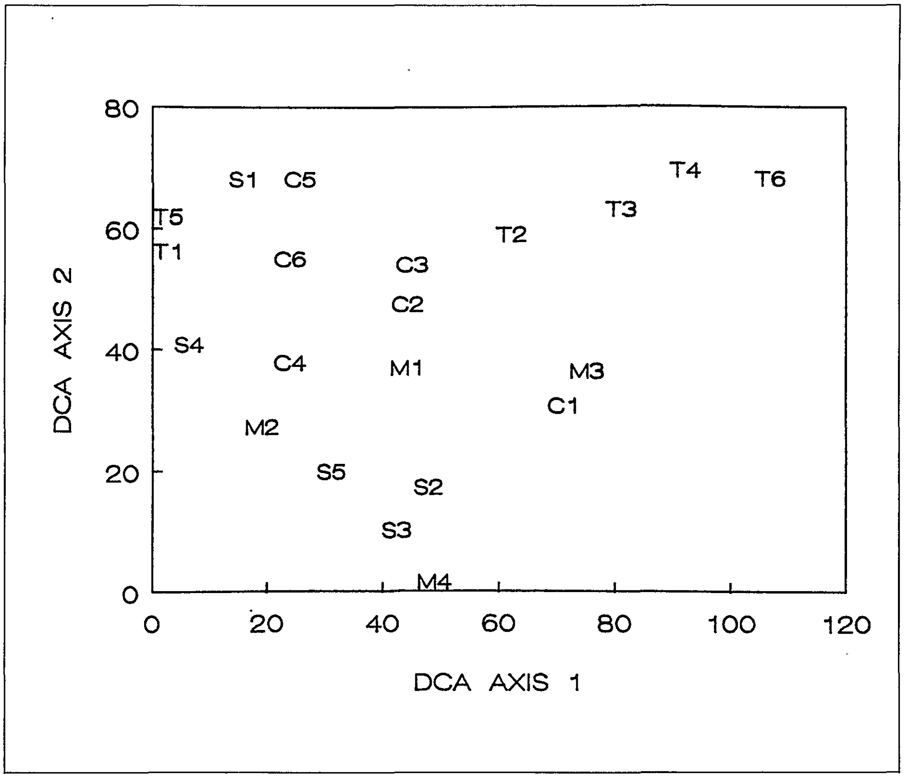

Figure 5. Detrended correspondence analysis (DCA) ordination of candidate stands based on 21 rescaled environmental/site variables.

Table 6a. Two-way indicator species classification table derived from percent stems/ha of species present in respective stands. Numbers in table refer to amount of species in the stand where: 1=0–1%, 2=2–4%, 3=5–9%, 4=10–19%, 5=20–100%. Hierarchal classifications according to stand groups (0, 1) are along the bottom of the table.

Species	Stands																				
	C1	C2	C5	C6	C3	M1	S2	S5	C4	M2	S1	S3	M3	M4	T2	S4	T3	T4	T1	T6	T5
MAGN ACU	-	-	-	5	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
NYSS SYL	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QUER COC	-	5	2	1	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PINU STR	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LIRI TUL	-	-	-	2	-	-	-	-	2	-	-	-	-	-	-	-	1	-	-	-	-
QUER VEL	1	1	2	2	1	-	3	1	-	-	2	1	-	-	-	-	-	-	-	-	-
QUER ALB	5	5	4	3	4	4	4	3	5	2	1	-	2	3	-	2	-	1	4	-	-
POPU GRA	1	-	2	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	4
DEAD SPP	-	2	3	2	4	2	-	3	4	-	-	-	-	3	1	4	2	1	-	4	2
QUER RUB	5	4	5	5	5	5	4	5	5	5	5	4	5	5	5	4	4	5	5	5	4
ACER RUB	2	4	4	3	-	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
ACER SAC	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	2	-
TSUG CAN	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-
BETU LEN	-	-	-	-	-	3	-	2	-	-	-	-	-	-	-	2	3	2	-	-	-
QUER PRI	5	2	3	3	-	-	-	-	-	-	-	-	3	-	-	-	4	4	3	5	5
FRAX AME	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	3	3	-
PRUN SER	-	-	-	-	-	-	-	-	-	-	-	-	2	-	4	-	1	-	-	-	-
FAGU GRA	-	-	-	-	-	-	-	-	-	-	-	-	3	4	2	-	-	-	-	-	-
ACER PEN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-
	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1
					0	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	1
																0	0	0	1	1	

Table 6b. Two-way indicator species classification table derived from percent basal area/ha of species present in respective stands.[1]

	Stands																				
Species	C4	C6	C1	C2	C5	C3	M1	M4	S4	S5	M2	S1	S2	M3	S3	T2	T1	T3	T4	T6	T5
MAGN ACU	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NYSS SYL	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QUER COC	-	2	-	5	3	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PINU STR	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LIRI TUL	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
TSUG CAN	1	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
QUER VEL	-	1	2	1	2	2	-	-	-	1	-	2	4	-	2	-	-	-	-	-	-
QUER ALB	4	2	5	5	4	4	4	3	3	3	3	2	4	2	-	-	3	-	1	-	-
QUER RUB	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
BETU LEN	-	-	-	-	-	-	2	-	2	2	-	-	-	-	-	-	-	2	1	-	-
DEAD SPP	3	2	-	1	3	3	2	3	4	2	-	-	-	-	-	2	-	1	1	3	2
ACER RUB	3	2	2	3	3	-	5	5	5	5	3	4	5	5	5	5	5	5	4	4	5
FAGU GRA	-	-	-	-	-	-	-	3	-	-	-	-	-	2	-	1	-	-	-	-	-
ACER SAC	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
POPU GRA	-	-	1	-	1	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	4
QUER PRI	-	3	5	2	3	-	-	-	-	-	-	-	-	2	-	-	3	4	5	4	5
FRAX AME	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	1	3	-
PRUN SER	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	4	-	2	-	-	-
ACER PEN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1
	0	0	1	1	1	1	0	0	0	0	1	1	1				0	0	0	0	1

[1]Numbers in table indicate amounts of species present as in Table 6a.

Table 6c. Two-way indicator species classification table derived from percent importance of species present in respective stands.

Species	C4	C2	C5	C6	C3	M1	M4	S4	S2	M2	S1	S2	S3	C1	T1	T4	T5	T6	M3	T2	T3
	Stands																				
LIRI TUL	3	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
MAGN ACU	2	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NYSS SYL	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
QUER COC	-	5	3	2	2	1		-	-	-	-	-	-	-	-	-	-	-	-	-	-
TSUG CAN	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
QUER VEL	-	1	2	2	1	-	-	-	1	-	2	4	2	1	-	-	-	-	-	-	-
QUER ALB	4	5	4	3	4	4	3	3	3	3	2	4	-	5	4	1	-	-	2	-	-
QUER RUB	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5
ACER RUB	4	4	4	3	-	5	5	5	5	4	4	5	5	2	5	5	5	4	5	5	5
BETU LEN	—	-	-	-	-	3	-	2	2	-	-	-	-	-	-	2	-	-	-	-	2
DEAD SPP	4	2	3	2	3	2	3	4	3	-	-	-	-	-	-	1	2	3	-	2	1
FAGU GRA	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	3	2	-
ACER SAC	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
POPU GRA	-	-	2	-	-	-	-	-	2	-	-	-	-	1	-	-	4	-	-	-	-
QUER PRI	-	2	3	3	-	-	-	-	-	-	-	-	-	5	3	5	5	5	2	-	4
FRAX AME	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	-	3	-	-	2
PRUN SER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4	2
PINU STR	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
ACER PEN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1
	0	1	1	1	1	0	0	0	0	1	1	1	1	0	1	1	1	1			

[1]Numbers in table indicate amounts of species present as in Table 6a.

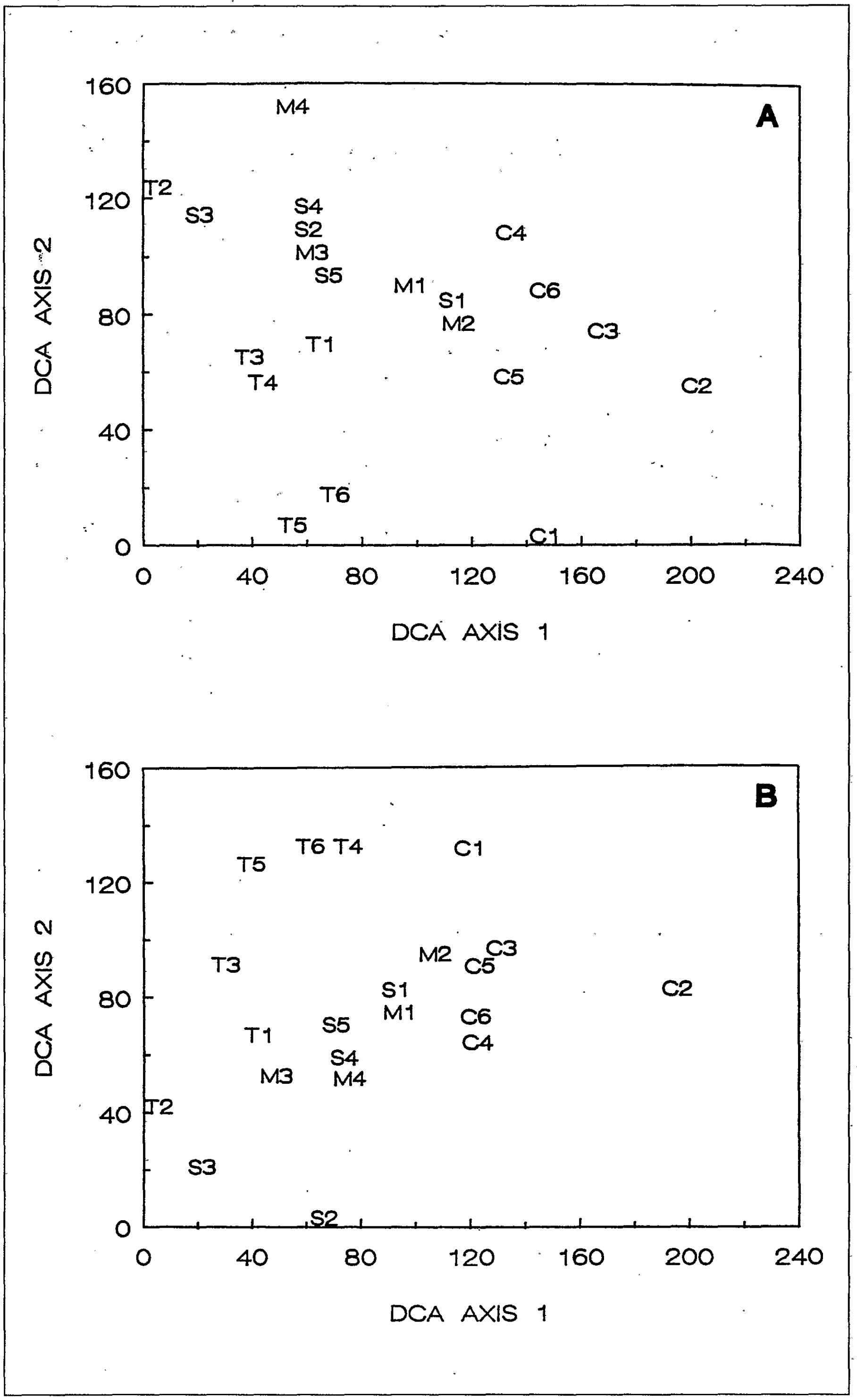

Figure 6. **A:** Detrended correspondence analysis (DCA) ordination of candidate stands based on stems/ha of canopy species.
B: DCA ordination of candidate stands based on basal area/ha of canopy species.

Table 7. Two-way indicator species stand classifications after the first division. Stand classifications were calculated based on stems/ha, basal area/ha, and importance value. Stands classified with the Clear Creek or west end of the gradient are denoted as group 0, and stands classified with the Tiadaghton or east end of the gradient are denoted as group 1.

	Core Area																				
	Clear Creek						Moshannon				Sproul					Tiadaghton					
	C1	C2	C3	C4	C5	C6	M1	M2	M3	M4	S1	S2	S3	S4	S5	T1	T2	T3	T4	T5	T6
	living and dead trees																				
Stems	0	0	0	0	0	0	0	1	1	1	1[1]	0	1	1[1]	0	1	1	1	1	1	1
Basal area	0	0	0	0	0	0	0	0	1	0[1]	0	0	1	0	0	1	1	1	1	1	1
Importance	1	0	0	0	0	0	0	0	1	0[1]	0	0	0	0	0	1	1[2]	1	1	1	1
	live trees only																				
Stems	0	0	0	0	0	0	1	1	1	1	1[1]	0	1	1	1	1	1	1	1	1	1
Basal area	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0[1]	1	1	1	1	1	1
Importance	0[1]	0	0	0	0	0	1[1]	1[1]	1	1	0	0	0	1	1	1	1	1	1	1	1

[1]Indicates the stand is classified with the group designated but it also lies in the zone of indifference and is therefore a borderline classification.
[2]Indicates the refined ordination places the stand to the left or right of the zone of indifference, but the indicator score would assign the stand to the opposite side and is therefore a misclassification.

gradient with stands from the eastern end of the gradient closest to each other at one end of the ordination and stands from the western end of the gradient closest to each other at the opposite end of the ordination. This relationship is prominent on the first DCA axis. A re-examination of the TWINSPAN classifications after the first division (Table 7) aids in identification of stands that are vegetationally most similar and geographically farthest apart. Stand M3 is the westernmost stand that is vegetationally most similar to stands in the Tiadaghton (eastern) core area. Although stand S1 is classified with stands in the Tiadaghton (eastern) core area using stems/ha, this classification is borderline for both live trees only and the analysis based on both dead trees as a single pseudospecies. Stand S1 is the easternmost stand with a vegetation composition most similar to stands in the Clear Creek (western) core area. Thus, stands M3 and S1 will permit comparisons of high and low deposition effects in stands having similar community structure.

Disturbance histories. Evaluation of stand disturbance histories focused on insect and disease events recorded by the Division of Forest Pest Management. Because of the qualitative nature of these data, only qualitative comparisons of stand disturbance events were appropriate. Information prior to the 1960's is scant or nonexistent. In the Clear Creek area of the gradient, information from the 1960's was not available; however, Bureau of Forestry entomologists claim that this area was not substantially affected by oak leafroller or oak leaftier during the 1960's.

Table 8 summarizes the information provided by the Division of Pest Management. The primary defoliators were oak leafroller, oak leaftier, and gypsy moth (*Lymantria dispar* (L.)). Oak leaftier outbreaks generally occurred in the period from 1964 to 1968, while oak leafroller outbreaks were detected in the period from 1968 to 1976. Gypsy moth defoliations were first reported for the Clear Creek stands in 1984 while stands in the Tiadaghton core area were defoliated by gypsy moth as early as 1980. In cases where surrounding stands were defoliated one mile or less from the candidate analogous stand, the defoliation event was assumed to also have occurred in the candidate stand. The Sproul, Tiadaghton, and eastern portion of the Moshannon core areas had a higher frequency of insect defoliation than the western part of the gradient. Stands in the Clear Creek core area have had the least insect defoliation. All additional studies

Table 8. Insect defoliation events summarized from microfilm sketch-map records by Pennsylvania Division of Pest Management personnel for the period 1960 to 1986. Insects identified as the primary defoliators are abbreviated as follows: oak leafroller=OLR, oak leaftier=OLT, gyspy moth=GM, fall cankerworm=FC, "oak defoliator"=OD.[1]

Stand	Number of years when defoliation occurred	Insects identified as the primary defoliators
Clear Creek[2]		
C1	3	OLR, *Pseudexentera* sp., GM
C2, C3	4	*Pseudexentera* sp., OD
C4	4	OLR, FC, GM
C5, C6	2	OLR, FC, *Pseudexentera* sp., GM
Moshannon		
M1	8	OLR, GM
M2	7	OLR, GM
M3	10	OLR, GM
M4	10	OLR, GM
Sproul		
S1	7	OLT, OLR, GM
S2	9	OLT, OLR, GM
S3	6	OLT, OLR, GM
S4	7	OLR, GM
S5	7	OLR, GM
Tiadaghton		
T1	10	OLT, OLR, GM
T2	7	OLT, OLR, GM
T3, T4	9	OLT, OLR, FC, GM
T5, T6	6	OLT, OLR, GM

[1]Oak leafroller=*Archips semiferanus* (Walker), oak leaftier=*Croesia semipurpurana* (Kearfott), gypsy moth=*Lymantria dispar* (L.), fall cankerworm=*Alsophila prometaria* (Harris).
[2]Defoliation records during the 1960's were not available for this area.

will consider the defoliation history of specific stands when interpreting the different measures of community productivity and community similarity/dissimilarity measures used to evaluate potential atmospheric deposition effects.

Synthesis of Site and Forest Community Analyses

Final stand selection involved consideration of results from all analyses with the objective of selecting the most similar stands. Ordinations of stand scores based on environmental and vegetation variables indicated that the most dissimilar stands were: C1, C2, M4, S2, S3, T1, T2, T4, T5, and T6. Elimination of these ten stands would leave 11 with reasonable similarity to assess atmospheric deposition impacts. However, the above list would require elimination of five of the six stands in the Tiadaghton core area. To meet the three stand per core area minimum, analyses were re-examined to determine which two of the five eliminated stands could be included.

Stand T1 was dissimilar only in the ordination based on environmental variables. However, because T1 has the lowest basal area of any stand (from thinning in the mid-1970's) and an atypical understory, it was not restored. Stand T4 was dissimilar from other stands based only on the ordination with environmental variables. Examination of the environmental ordination (Fig. 5) shows that T4 is 'close' to stand T3. On this basis stand T4 was restored. Both stands T5 and T6 were dissimilar from other stands based on ordinations on stand scores of stems/ha. Stand T6 has the highest basal area/ha (31.3 m2/ha) of any stand, and a low site index, 18.1. It also has an atypical sugar maple component and greater number of dead trees than stands T3, T4, and T5. For these reasons, T6 was not restored. Jackknifed classifications (Table 5) using B_1 and topographic discriminant functions misclassified stand T5 into core areas 1 or 2. For this reason and because of a greater overall similarity (site index, species composition) to stands T3 and T4, stand T5 was restored. The following 13 stands were considered analogous after all comparisons: C3, C4, C5, C6, M1, M2, M3, S1, S4, S5, T3, T4, T5. All subsequent analyses and interpretations must necessarily consider the inherent dissimilarity of the two restored stands, as well as unique attributes identified in other selected stands.

It is important to note that stands T3, T4, T5, and T6 occur on soils that formed in glacial till (Soil Conservation Service 1986). These are the only stands along the gradient with soils of glacial origin. Although this may account for some of the vegetational dissimilarity of these stands compared to the other stands, previous research in Potter County, Pennsylvania did not indicate major vegetation changes upon crossing the boundary of the Wisconsin drift (Goodlet 1954).

Table 9 summarizes the ordinations and reasons for similarity/dissimilarity classifications for the 21 candidate stands. The 13 selected analogous stands provide substantial overlap of both vegetation and environmental or site characteristics. With the exception of stands T3, T4, and T5 in Lycoming County, the selected stands are also in close proximity to deposition monitoring sites. This will enable accurate characterization of wet deposition inputs for most stands.

Assessment/Verification of Stand Comparability

Additional intensive sampling of the 13 selected stands provided a basis for verifying the initial stand selection procedures. These initial procedures focused on overstory species composition, soil physical characteristics, and topographic variables. These variables were subsequently re-examined using the expanded data obtained from the intensive sampling of each stand.

Analysis of environmental/site variables. Centroid cluster analyses revealed slightly different relationships among stands and environmental variables than were observed in the selection process. While there was no tendency for stands from core areas to consistently cluster together, stand M1 was an outlier (the last stand to cluster with all previous cluster groups) in the analysis based on A horizon soil variables (Fig. 7a). Stand M1 had the highest percent sand (54.2%) in the A horizon compared to all other 12 stands. In the B1-horizon cluster analysis (Fig. 7b), stands from the Tiadaghton core area did not cluster together as they did in the initial selection cluster analysis (Fig. 4b).

Stepwise discriminant analyses revealed there were significant discriminant functions for B_1 and B_2 horizon variables and for topographic variables (Table 10). As with the discriminant functions described in the selection process, these functions were generally quite poor with high rates of misclassified observations. For both the B_1 and B_2 horizon discriminant functions the thickness of the respective horizon was the only variable to enter, and only six of the 13 stands were correctly classified

Table 9. Summary of similarity/dissimilarity classifications for 21 stands based on ordinations of site and vegetation variables.

Stand	DCA Ordination[1] Site vars.	Stems/ ha	Basal area/ha	Classification[2] S/D	Stand Selected Y/N	Comments
C1	C	P	C	D	N	Dissimilar vegetation
C2	C	P	P	D	N	Dissimilar vegetation
C3	C	C	C	S	Y	
C4	C	C	C	S	Y	
C5	C	C	C	S	Y	
C6	C	C	C	S	Y	
M1	C	C	C	S	Y	
M2	C	C	C	S	Y	
M3	C	C	C	S	Y	
M4	P	P	C	D	N	Dissimilar site, vegetation-stems/ha
S1	C	C	C	S	Y	
S2	C	C	P	D	N	Dissimilar vegetation-BA/ha, disturbance
S3	C	P	P	D	N	Dissimilar vegetation-BA/ha, disturbance
S4	C	C	C	S	Y	
S5	C	C	C	S	Y	
T1	P	C	C	D	N	Dissimilar site, disturbance
T2	C	P	P	D	N	Dissimilar vegetation
T3	P	C	C	D	Y	Dissimilar site
T4	P	C	C	D	Y[3]	Dissimilar site, similar to stand T3
T5	P	P	C	D	Y[3]	Dissimilar site, vegetation
T6	P	P	C	D	N	

[1]C or P refers to whether the stand was centrally or peripherally located on the ordination.
[2]S or D refers to whether the stand was considered similar or dissimilar based on all ordinations.
[3]This stand was retained to provide three stands per core area.

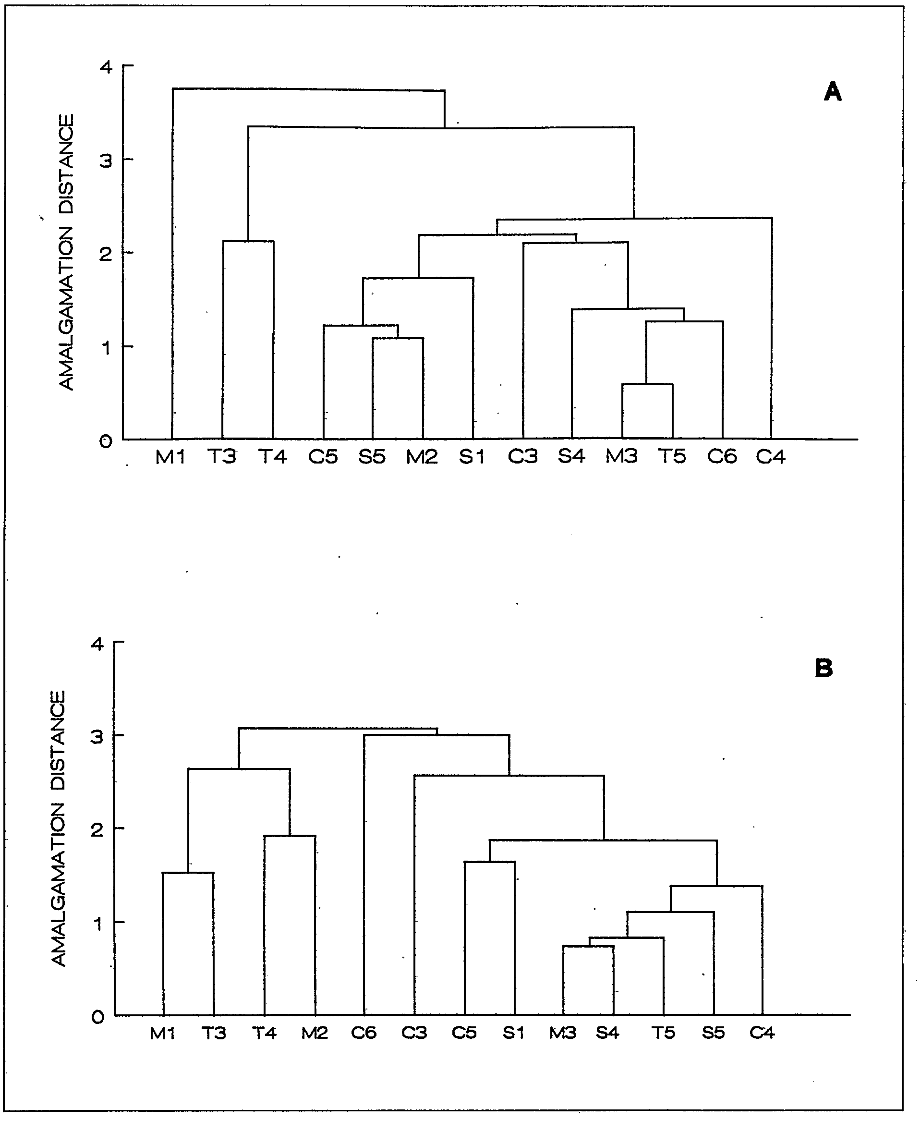

Figure 7. **A:** Dendrogram of centroid cluster analysis based on A horizon soil variables. **B:** Dendrogram based on B_1 horizon soil variables.

Table 10. Summary of jackknifed classifications derived from discriminant functions for B_1 and B_2 horizon and topographic variables. Numbers indicate the core area where the stand was classified: 1=Clear Creek, 2=Moshannon, 3=Sproul, 4=Tiadaghton.

		Discriminant Function		
Core Area	Stands	B_1	B_2	Topographic
Clear Creek	C3	3	4	1
	C4	1	3	4
	C5	1	3	1
	C6	1	1	4
Moshannon	M1	2	2	2
	M2	2	2	3
	M3	4	2	2
Sproul	S1	1	1	1
	S4	4	2	2
	S5	4	4	3
Tiadaghton	T3	3	4	3
	T4	2	3	1
	T5	4	4	1
Total % Correct Classifications		46.2	46.2	38.5

with each discriminant function. The topographic discriminant function included elevation as the only significant variable to enter and only five of the 13 stands were correctly classified into the correct core area.

Stand scores for the 18-rescaled environmental variables are plotted on the first two DCA axes (Fig. 8). Stand T4 is the most peripherally located, while the remaining 12 stands show no evidence of an underlying environmental gradient. Stand T4 was also peripherally located in the environmental variable ordination used during the selection process (Fig. 5)

Analysis of vegetation variables. The analysis of variance (Table 11) of stand density (stems/ha) and stocking (basal area/ha) of live trees revealed significant ($P < 0.05$) variability for number of stems/ha in the overstory and no significant variation associated with basal area/ha (Table 12). The variability among stands nested in core areas for number of stems/ha was significant ($P < 0.05$) while the variability among core areas was not. Both core areas 1 and 2 had significant ($P < 0.03$) variability among stands within each respective core area. In core area 1 stand C4 had the lowest density, 243.1 trees/ha while stand C5 had the highest density, 333.8 trees/ha. Similarly in core area 2, M2 had the lowest density, 252.0 trees/ha and M1 was highest with 316.1 trees/ha.

DCA ordinations based on stand averaged stems/ha of overstory trees (Fig. 9) indicate stand T5 is peripherally located. Stand T5 was the only stand to have an overstory component of eastern hemlock (*Tsuga canadensis* Carr.) and eastern white pine (*Pinus strobus* L.) though each species composed 1% or less of the total stems/ha. This stand also had a large chestnut oak and black birch component. The DCA ordination also indicates stands C3 and C5 are dissimilar from the other stands based on their separation along axis 2. A similar result was observed in the same ordination during the stand selection process (Fig. 6a). The TWINSPAN classification (Table 13a) based on overstory stems/ha indicated the initial clustering of stands C3, C5, and C6. The major reason for this grouping was apparently the unique presence of overstory scarlet oak in these stands and relatively fewer red maple stems.

The variability based on stand averaged basal area/ha was considerably less than the stems/ha DCA ordination. Again stands T5 and C3 were peripheral in the DCA ordination (Fig. 10). The TWINSPAN classification (Table 13b) again identifies C3, C5, and C6 as a distinct group at the first division. Stands C5 and C6 have considerably less basal area/ha of overstory red maple, as well as the differences mentioned above.

More detailed ordinations and classifications based on the overstory composition of individual plots (n=160) were also examined. The DCA ordinations (Fig. 11a) indicate substantial overlap of the plot vegetation characteristics. There is a tendency in the stems/ha ordination for the Tiadaghton core area plots to have greater variation along axis 2 than the plots in other core areas.

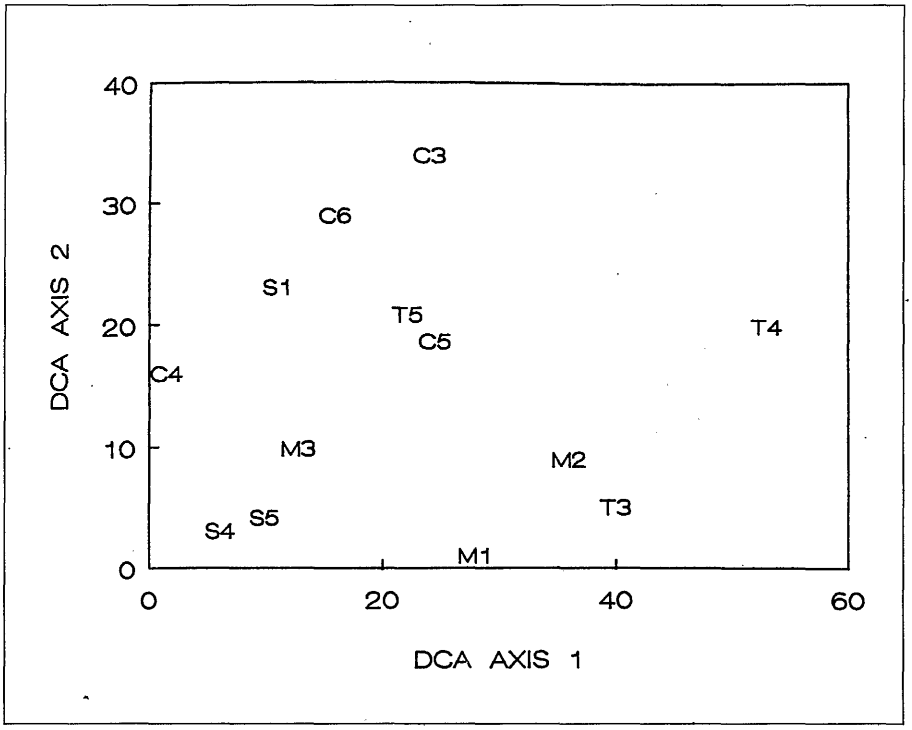

Figure 8. Detrended correspondence analysis (DCA) ordination of 13 analogous stands based on 18 rescaled environmental/site variables.

Table 11. Analysis of variance F-statistics (associated probability levels) for stems/ha and basal area/ha amounts compared among core areas and stands nested in core areas. Results assume models with fixed effects for all factors.

Analysis	Overall Model F-statistic[1]	Core Area F-statistic[2]	Stands (Core Area) F-statistic[3]
Living overstory trees			
Stems/ha	1.96 (.032)	1.82 (.146)	2.00 (.043)
Basal area/ha	1.54 (.116)	2.85 (.040)	1.14 (.338)
All dead trees			
Stems/ha	4.62 ($<$.0001)	8.69 ($<$.0001)	4.17 ($<$.0001)
Basal area/ha	3.80 (.0005)	3.48 (.018)	3.42 (.0008)

[1]Degrees of freedom are 12, 159
[2]Degrees of freedom are 3, 147
[3]Degrees of freedom are 9, 147

Table 12. Live overstory stand stocking and density determined from 12-m-radius plots samples in each stand.

Core Area	Stand	Code	Stems/ha	Basal Area
			—no./ha-	—m2/ha
1	Sigel 7	C3	256.4	24.7
	Munderf 1	C4	243.1	28.9
	Munderf 2	C5	333.8	25.4
	Munderf 5	C6	256.4	28.7
	Average		**272.4**	**26.9**
2	Huntley 1	M1	316.1	25.0
	Huntley 2	M2	252.0	24.2
	E. Park 2	M3	285.1	25.6
	Average		**284.3**	**24.8**
3	Glen Union 1	S1	271.9	25.4
	H. Fork 2	S4	311.7	19.7
	H. Fork 3	S5	291.8	23.8
	Average		**291.8**	**23.1**
4	Bodines 1	T3	316.1	26.5
	Bodines 2	T4	305.0	25.6
	Trout Run 2	T5	320.5	24.1
	Average		**313.9**	**25.4**

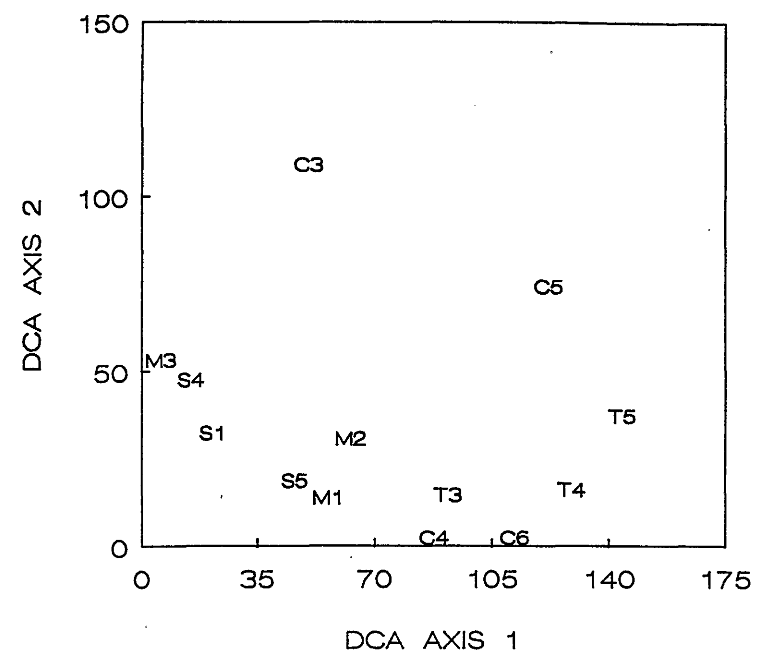

Figure 9. Detrended correspondence analysis (DCA) ordination of 13 analogous stands based on stems/ha of canopy species.

Table 13a. TWINSPAN classification table derived from percent stems/ha of overstory species present in 13 stands. Hierarchal classifications according to stand groups (0, 1) are along the bottom of the table. See Table 6 for details.

Species	STANDS												
	S4	T3	T4	T5	M1	M2	M3	S5	S1	C4	C5	C6	C3
TSUG CAN	-	-	-	1	-	-	-	-	-	-	-	-	-
BETU ALL	-	1	-	-	-	-	-	-	-	-	-	-	-
OSTR VIR	-	-	1	-	-	-	-	-	-	-	-	-	-
PINU STR	-	-	-	1	-	-	-	-	-	-	-	-	-
BETU PAP	2	1	-	-	-	-	-	-	-	-	-	-	-
FRAX AME	-	2	2	-	-	-	-	-	-	1	-	-	-
ACER SAC	-	-	2	-	-	-	-	-	-	2	-	-	-
QUER VEL	-	-	-	-	1	-	-	-	-	-	-	-	-
SASS ALB	-	-	-	-	1	-	-	1	-	-	-	-	-
ROBI PSE	-	-	-	-	-	-	-	-	2	-	-	-	-
FAGU GRA	1	-	-	1	-	1	2	-	-	-	-	-	-
POPU GRA	-	1	1	2	-	1	-	3	-	2	-	-	-
PRUN SER	-	-	-	-	-	1	1	-	-	-	-	1	-
QUER RUB	4	5	5	4	5	5	5	5	5	5	5	5	5
ACER RUB	5	5	3	5	5	5	5	5	5	4	3	2	4
LIRI TUL	-	2	-	-	2	1	-	-	-	3	-	3	-
QUER ALB	3	2	3	2	3	4	4	4	3	4	3	1	5
BETU LEN	4	1	1	3	1	1	-	1	-	-	-	-	2
QUER PRI	2	3	5	5	2	1	-	1	-	-	4	3	1
MAGN ACU	-	-	-	-	1	1	1	-	-	1	2	3	-
AMEL SPP	-	-	-	-	-	-	-	-	1	-	1	-	-
CARY GLA	-	-	1	-	-	-	-	-	-	1	-	1	1
NYSS SYL	-	-	-	1	-	-	-	-	-	-	1	-	1
CARY OVA	-	-	-	-	-	-	-	-	-	-	1	-	-
QUER COC	-	-	-	-	-	-	-	-	-	-	4	1	4
Classification	0	0	0	0	0	0	0	0	0	0	1	1	1
	0	0	0	0	1	1	1	1	1	1			
					0	0	0	0	0	1			
					0	0	0	0	1				

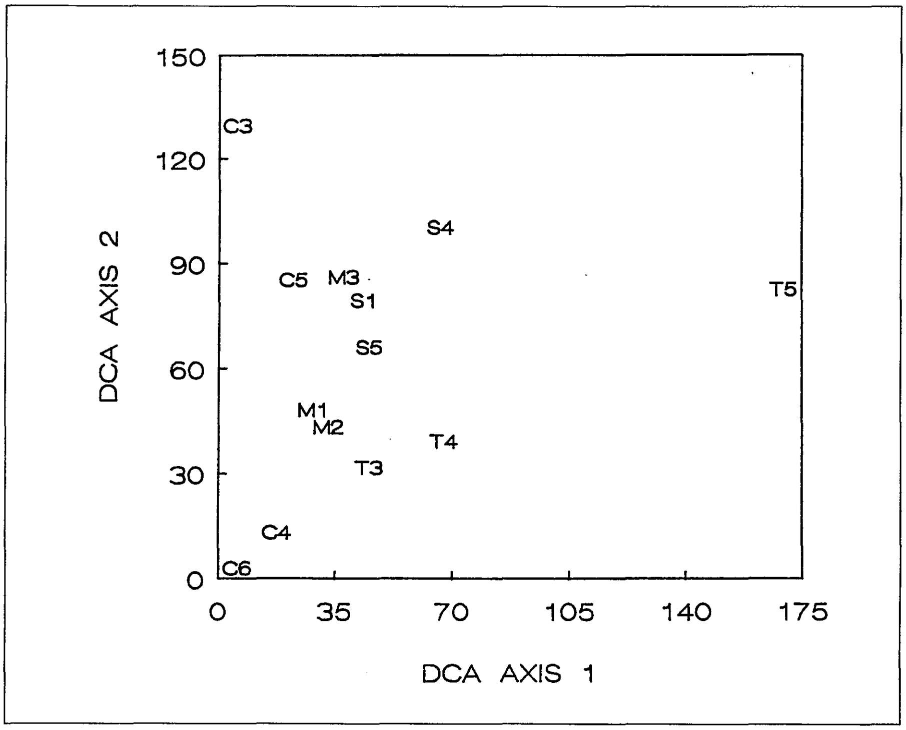

Figure 10. DCA ordination based on basal area/ha of canopy species.

The ordination based on individual plot overstory basal area indicates that five plots in core area 4 (stand T5) and approximately 7 plots from core area 1 stands could be considered outliers (Fig. 11b). However, substantial overlap of community composition is evident in both of these ordinations.

The TWINSPAN classification based on the plot averaged data also indicated considerable overlap in community characteristics. At the first division based on stems/ha (not shown) stands C5, C6, and T4 each had 8 or more of their 10 plots classified in one group. Plot classification within this group was associated with the presence of tuliptree (*Liriodendron tulipifera* L.), cucumber tree (*Magnolia acuminata* L.), and scarlet and chestnut oaks. These plots also had relatively less stems/ha of red maple. For the classification based on overstory basal area/ha, the amount of chestnut oak was important in placing plots in one group at the first division. Stands C5, C6, T4, and T5 all had 8 or more plots in one group at the first division. For both classifications the second group at the first division was dominated by plots in stands located in core area 3 where red maple was a frequent overstory species.

Integrating the results of the DCA and TWINSPAN analyses based on stand averaged data (Table 14) reveals that stands C5 and C3 are consistently different in most analyses. Stand T5, while obviously different in the ordinations, was not as evidently different in the TWINSPAN classification results. While the ordinations suggest that stand T5 is an outlier there is still substantial evidence of community similarity with the other stands such as T4 in the stems/ha DCA ordination. The consistent grouping of C3 and C5 with C6 at the first division in the TWINSPAN classification suggests some unique community characteristics; however, there is still substantial overlap with vegetation characteristics of the other stands.

Comparison of selection and verification analyses. The verification analyses confirm the substantial overlap of forest community vegetation which was initially identified with less intensive sampling during the stand selection process. With additional sampling and more detailed analyses, more differences were apt to become evident. However, with the increased sampling intensity, and decreased number of stands sampled (from 21 to 13), the overall variation could be expected to decrease.

The environmental/site verification analyses indicate that the variation among the 13 selected stands was substantially less than the variation in the original 21 stand set. This is evidenced in the ordinations based on the rescaled soil and topographic variables. Stand T4 looks the most dissimilar in the verification ordination (Fig. 8), but the overall variability along DCA axis 1 is approximately half the variability associated with the selection ordination (Fig. 5). Similarly, the discriminant functions selected for the verification analyses using B_1, B_2, and topographic variables were very poor in properly classifying stands into their correct core areas.

The verification analyses of vegetation variables revealed some different aspects of stand composition not observed in the selection process. In general, the verification DCA ordinations based on stems/ha (Fig. 9) had less variability along both DCA axes than was observed in the selection ordination (Fig. 6a). Stands C3 and C5 are the most peripherally located in the verification ordination; this was also indicated in the selection ordination.

The verification ordination based on basal area/ha indicates less variation along the DCA axis 1 (Fig. 10) than was observed with the selection ordination (Fig. 6b). The peripheral location of stand T5 in the verification ordination was suggested in the selection ordination; however, stand T4 is more centrally located in the verification than in the selection ordination. Conversely, stand C3 was more centrally located in the selection ordination than in the verification ordination.

The TWINSPAN verification classification based on stems/ha showed three of the four Clear Creek core area stands, C3, C5, and C6, clustering in an initial group (Table 13a). The selection classification put all four stands in the same group at the first division (Table 6a). Stand C4 clustered with the remaining stands in the verification classification at the first division. Stands M1 and S5, which clustered with the Clear Creek stands in the selection classification, clustered with stand C4 and the remaining stands in the verification classification. A major aspect of the differences between the selection and verification classifications is the increased amounts of red maple and scarlet oak which were sampled in stands C3, C5, and C6 compared to the amounts which were sampled in the preliminary (i.e. selection) sampling.

Table 13b. TWINSPAN classification table derived from percent basal area/ha of overstory species present in 13 stands. See Table 6 for details.

STANDS Species		C4	T3	T4	T5	S4	M2	M3	S1	S5	M1	C5	C6	C3
FRAX	AME	1	2	1	-	-	-	-	-	-	-	-	-	-
ACER	SAC	1	-	1	-	-	-	-	-	-	-	-	-	-
TSUG	CAN	-	-	-	1	-	-	-	-	-	-	-	-	-
BETU	ALL	-	1	-	-	-	-	-	-	-	-	-	-	-
OSTR	VIR	-	-	1	-	-	-	-	-	-	-	-	-	-
PINU	STR	-	-	-	1	-	-	-	-	-	-	-	-	-
POPU	GRA	2	1	1	3	-	1	-	-	3	-	-	-	-
BETU	PAP	-	1	-	-	1	-	-	-	-	-	-	-	-
QUER	VEL	-	-	-	-	-	-	-	-	-	2	-	-	-
FAGU	GRA	-	-	-	1	1	1	2	-	-	-	-	-	-
SASS	ALB	-	-	-	-	-	-	-	-	1	1	-	-	-
ROBI	PSE	-	-	-	-	-	-	-	1	-	-	-	-	-
ACER	RUB	2	4	2	4	5	4	5	5	5	4	1	1	4
BETU	LEN	-	1	1	2	4	1	-	-	1	1	-	-	1
PRUN	SER	-	-	-	-	-	1	1	-	-	-	-	1	-
QUER	RUB	5	5	5	4	5	5	5	5	5	5	5	5	5
QUER	ALB	3	2	3	2	4	3	4	3	4	3	3	1	5
QUER	PRI	-	3	4	5	2	1	-	-	1	2	3	2	1
MAGN	ACU	1	-	-	-	-	1	1	-	-	1	2	2	-
AMEL	SPP	-	-	-	-	-	-	-	1	-	-	1	-	-
NYSS	SYL	-	-	-	1	-	-	-	-	-	-	1	-	1
CARY	OVA	-	-	-	-	-	-	-	-	-	-	1	-	-
QUER	COC	-	-	-	-	-	-	-	-	-	-	4	1	5
LIRI	TUL	3	2	-	-	-	1	-	-	-	2	-	4	-
CARY	GLA	1	-	1	-	-	-	-	-	-	-	-	1	1
Classification		0	0	0	0	0	0	0	0	0	0	1	1	1
		0	0	0	0	1	1	1	1	1	1			
						0	0	0	0	0	1			
						0	1	1	1	1				

The TWINSPAN verification classification based on basal area/ha differed from the selection classification but tended to mirror the verification classification based on stems/ha. Stands C3, C5, and C6 again clustered at the first division while stand C4 clustered with the remaining stands (Table 13b). In the selection classification (Table 6b) all four stands clustered at the first division. The reasons for this difference are related to the increased amounts of red maple and scarlet oak as described previously. It is important to recognize that stands C3, C5, and C6

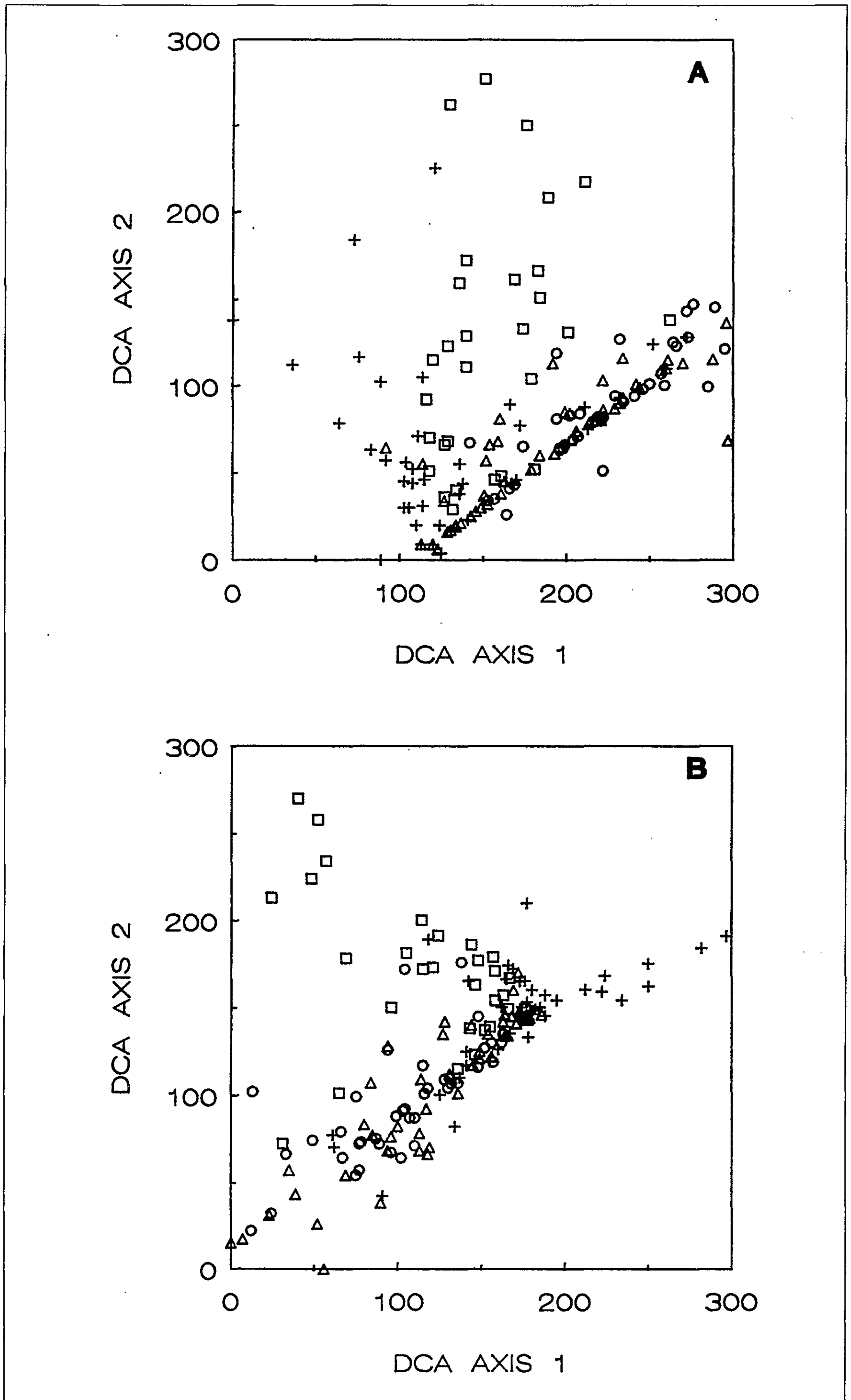

Figure 11. **A:** Detrended correspondence analysis (DCA) ordination of plot scores (n=160) from each core area based on stems/ha of canopy species. Core area 1=plus; core area 2=triangle; core area 3=circle; core area 4=square. **B:** DCA ordination of plot scores based on basal area/ha of canopy species.

still have significant characteristics in common with the other ten stands. This is substantiated in part by their location in the DCA ordination based on basal area/ha (Fig. 10). An overall assessment of the verification results indicates that they do not differ appreciably from the selection results.

Summary and Recommendations

Field studies often contend with many uncontrolled variables which have the potential to confound observed responses (Peterman 1990). The selection of ecologically analogous stands involves minimizing extraneous variation among sites so that relevant hypotheses can be more rigorously evaluated. By limiting site-to-site variation the possibility of detecting small treatment differences or responses is enhanced. In addition, with the procedures described herein, a detailed knowledge of relative stand homogeneity and quantitative estimates of the variance structure of relevant variables are available. Thus, hypothesis testing and the relative confidence associated with acceptance/rejection decisions can be conducted with a comprehensive knowledge of stand attributes and their variation. A brief comparison of other studies evaluating deposition effects along well-defined gradients may indicate both the strengths and weaknesses of this approach.

A gradient of wet sulfate deposition in Minnesota, Wisconsin, and Michigan has been used to evaluate atmospheric deposition effects on forest soils and vegetation. One study using randomly selected U.S. Forest Service Forest Inventory and Analysis plots in a variety of forest vegetation and soil types found significantly greater amounts of total S, adjusted for total N, in forest floor and mineral soil compartments sampled in the high deposition portion of the gradient compared to those in the low deposition zones (David et al. 1988). In this study no effort was expended to select ecologically analogous sites. Instead, a random sampling approach with a high sampling intensity was used (169 randomly selected plots and over 2500 soil and forest floor samples). Such an approach is warranted where resources are sufficient.

Table 14. Summary DCA ordinations and TWINSPAN classifications based on stand averaged data from overstory trees.

	DCA[a]		Twinspan[b]	
Stand	Stems/ha	BA/ha	Stems/ha	BA/ha
C3	P	P	1	1
C4	C	C	0	0
C5	P	C	1	1
C6	C	C	1	1
M1	C	C	0	0
M2	C	C	0	0
M3	C	C	0	0
S1	C	C	0	0
S4	C	C	0	0
S5	C	C	0	0
T3	C	C	0	0
T4	C	C	0	0
T5	P	P	0	0

[a] P=peripherally located on ordination
C=centrally located on ordination
[b] 0=first group of first division
1=second group of first division

Using essentially the same gradient, but limited to Wisconsin, Bockheim et al. (1989) did not detect significant differences in chemical composition of red pine foliage and forest floors sampled in relatively uniform plantations. In this case three red pine plantations in each of five areas were selected to minimize the variation with regard to age, initial stocking, number of thinnings, site index, basal area, and soils across the deposition gradient. However, these factors were apparently not quantitatively compared until after the sites were selected. Thus for the growth parameters such as site index, 5-yr intercept, and annual radial increment (mm/yr), variation within sites was larger than variation among sites. In this case a slightly more rigorous selection methodology and quantitative comparisons prior to site selection may have aided in selecting more ecologically analogous stands, assuming such stands and appropriate resources were available.

Comparison of selection and verification analyses in our study indicate some potential inadequacies in the selection methodology. Stand boundaries should be clearly determined during the selection process so the sampling transect can be quickly established to efficiently sample the stand. Stand boundaries were more carefully delineated after stand selection and prior to random selection of plot centers. This process permitted thorough characterization of stand composition after selection; however, some of this effort could have been focused on more thorough sampling of candidate stands. Slightly more intensive soil sampling would also help to characterize the potential variability across the range of stand conditions. Again, establishing stand boundaries prior to sampling would be advantageous. As with many studies, sampling intensity is frequently controlled by financial and time constraints. Thus, the effort required to clearly establish stand boundaries in the selection phase may prove unfeasible in many situations.

This approach to analogous site selection combined objective, quantitative elements with experience and knowledge of the investigators. The quantitative aspect documents the relationship of selected sites within the context of all identifiable nominally analogous sites. The relatively low sampling intensity used in this example proved quite adequate for selecting analogous sites. Thus, the technique also provided an *a priori* estimate of the ecological similarity of the sites, as well as an indication of attributes most dissimilar among the selected sites.

Some other studies may have benefited from a similarly rigorous site selection procedure (e.g., McClenahen and Brown 1988; Bockheim et al. 1989) assuming adequately analogous sites were available. However, any benefit of the rigorous selection procedure used in our study will only be evident upon investigation of relationships of response variables with atmospheric deposition and site variation not accounted for by the site selection procedures or statistical means.

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